

1 **CCSP Synthesis and Assessment Product 1.2**

2 **Past Climate Variability and Change in the Arctic and at High**

3 **Latitudes**

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5 **Chapter 3 - Preface: Report Motivation and Guidance for Using this Synthesis and**

6 **Assessment Report**

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3.1 Introduction

The U.S. Climate Change Science Program (CCSP), a consortium of Federal agencies performing climate science, has established a Synthesis and Assessment program as part of its Strategic Plan. A primary objective of the CCSP is to provide the best science-based knowledge possible to support public discussion and government- and private-sector decision making on the risks and opportunities associated with changes in the climate and related environmental systems (U.S. Climate Change Science Program, 2007). The CCSP has identified an initial set of 21 Synthesis and Assessment Products (SAPs) that address the highest-priority research, observation, and decision-support needs to advance decision making on climate change-related issues. This assessment, SAP 1.2, focuses on the evidence for and record of past climate change in the Arctic. This SAP is one of 3 reports that address the climate-variability-and-change research element and Goal 1 of the CCSP Strategic Plan to improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change.

One of the primary goals of the climate research element and of Goal 1 of the CCSP is to better understand natural, long-term cycles in climate. The Arctic region of the Earth, by virtue of its sensitivity to the impacts of climate change through strong climate feedback mechanisms, has a particularly informative paleoclimate record. Mechanisms operating in the Arctic and at high northern latitudes are also linked to global climate mechanisms; thus, an examination of how Arctic climate has changed in the past is globally informative.

3.2 Motivation for this Report

3.2.1 Why does the past matter?

Paleoclimate records play a key role in understanding the Earth's past and present climate system and in predicting future climate changes. This role is recognized, for example, by inclusion of paleoclimate as Chapter 6 of the 11-chapter Fourth Assessment Report of Working Group I (AR4-I) of the Intergovernmental Panel on Climate Change (IPCC), and by the extensive references to paleoclimatic data in climate change reports of the U.S. National Research Council, such as *Climate Change Science: An Analysis of Some Key Questions* (Cicerone et al., 2001). The perspective provided by paleoclimate data plays several roles in the effort to understand and predict the behaviors of the Earth's climate system. Paleoclimate data help to elucidate past and present active mechanisms by placing the short instrumental record in a longer-term context and by permitting model testing beyond the time-limited period of instrumental records. Paleorecords also provide quantitative estimates of the magnitude of the polar amplification of climate change. These estimates can also be used to evaluate polar amplification derived from model simulations of past and future climate changes.

The pre-instrumental context of the Earth's climate system provided by paleo-data strengthens the interlocking web of evidence supporting scientific results regarding climate change. For example, in considering whether fossil-fuel burning is an important contributor to the recent rise in atmospheric carbon-dioxide concentrations, it is important to determine and quantify global sources and sinks of carbon in the Earth's overall carbon budget. But one can also legitimately ask whether the change of atmospheric carbon-dioxide concentrations observed in the instrumental record for the past 100 years falls

inside or outside the range of natural variability as revealed in the paleo-record, and if inside, whether the timing of changes in carbon dioxide levels matches any known natural cycles that can explain them. Answers to such questions must come from paleoclimate data, because the instrumental record is much too short to characterize the full range of natural fluctuations.

Testing and validation of climate models involves several techniques, as described in Chapter 8 of IPCC AR4-I. The specific role of paleoclimate information is described there: “Simulations of climate states from the more distant past allow models to be evaluated in regimes that are significantly different from the present. Such tests complement the ‘present climate’ and ‘instrumental period climate’ evaluations, since 20th century climate variations have been small compared with the anticipated future changes under forcing scenarios derived from the IPCC *Special Report on Emission Scenarios* (SRES).”

3.2.2 Why the Arctic?

Over the past century the planet has shown an overall warming of 0.74 [0.56 to 0.92]°C (IPCC, 2007). Over land areas in the Arctic, a warming trend in air temperatures of as much as 3°C (exceeding 4°C in winter; Serreze and Francis, 2006) has been experienced over the same period of time. Instrumental records indicate that over the past 30 years, average temperatures in the Arctic have increased at almost twice the rate of the planet as a whole. Attendant changes include reduced sea ice, reduced glacier extent, increased coastal erosion, changes in vegetation and wildlife habitats, and permafrost degradation. Global climate models incorporating the current trend of

increasing greenhouse gases project continued warming in the near future and a continued amplification of global signals in the Arctic. The sensitivity of the Arctic to changed forcing is due to powerful positive feedbacks in the Arctic climate system. These feedbacks produce large impacts on Arctic climate while also having significant impacts on the global climate system. This high degree of sensitivity makes the paleoclimate history of the Arctic especially informative when considering the issue of modern climate change. Summaries of recent Arctic environmental change (e.g., Correll, 2004; Richter-Menge et al., 2006) are primarily based on observations and instrumental records. This report utilizes paleoclimate records to provide a longer-term context for recent Arctic warming in order to better understand the potential for future climate changes. Paleoclimate records provide a mechanism to define the range of past natural variability in the Arctic and the magnitude of polar amplification, to evaluate the past rates of Arctic climate change (and thereby provide a long-term context for current rates of change), and to identify past Arctic warm states that are potential analogs of future conditions. The paleoclimate record also permits quantification of the impacts of abrupt perturbations (e.g., large injections of volcanic ash into the atmosphere) and threshold behaviors, and offers insights into how the Arctic has behaved during past warm times by identifying critical feedbacks and their mechanisms.

3.3 Focus and Scope of this Synthesis Report (Geographic and Temporal)

The content of this report follows from the prospectus developed early in its planning (this prospectus is available at the CCSP website – <http://www.climatescience.gov>), and is focused on four topical areas in which the lead

107 authors believe that consideration of the paleo-record can most strongly inform
108 discussions of climate change. These topics, each addressed in a separate chapter of this
109 synthesis report, are:

- 110 1. The history of past changes in Arctic temperature and precipitation;
- 111 2. Past rates of change in the Arctic;
- 112 3. The paleo-history of the Greenland Ice Sheet; and
- 113 4. The paleo-history of sea ice in the Arctic.

114 In general, the temporal scope of this report covers the past 65 million years of the
115 Earth's climate history from the early Cenozoic (65 Ma ago) to the recent Holocene
116 (today). Each chapter presents information in chronological sequence from oldest to
117 youngest. The level of detail in the report generally increases as one moves forward in
118 time as a natural consequence of the increased availability of more and more-highly-
119 resolved paleo-records as one approaches the present. The geographic scope of this
120 report, while focused on the Arctic, includes some sub-Arctic areas – especially in and
121 near the North Atlantic – in order to entrain many relevant, high-quality paleo-records
122 from these regions.

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124 The specific questions posed in the report are:

125 ***1) How have temperature and precipitation changed in the Arctic in the past? What***
126 ***does this tell us about Arctic climate that can inform projections of future changes?***

127 This report documents what is known of high-latitude temperature and
128 precipitation during the past 65 million years at a variety of time scales, using
129 sedimentary, biological and geochemical proxies largely from ice cores, lake sediment,

and marine sediment records, as well as sediments found in river and coastal bluffs and elsewhere. Sedimentary deposits do not record climatological data in the same way that a modern scientific observer does, but climatic conditions control many characteristics of many sediments, so these sedimentary characteristics can serve as proxies – indirect recorders – for the climate that produced them (e.g., Bradley, 1999). Many proxies are used routinely (see Chapter 4 for a discussion of proxies), including the character of organic matter, the isotopic geochemistry of minerals or ice, the abundance and types of macro and micro fossils, and occurrence and character of specific chemicals (biomarkers) indicative of the presence or absence of certain species and of the conditions under which those species grew. Historical records taken from diaries, notebooks, and logbooks are also commonly used to link modern data and paleoclimate reconstructions.

The proxy records document large changes in the Arctic. As described in chapter 5, comparison of Arctic paleoclimatic data to records from lower-latitude sites for the same times shows that Arctic temperature changes have been amplified. This Arctic amplification occurred for climate changes with different causes. Physical understanding shows that this amplification is a natural consequence of features of the Arctic climate system.

2) How rapidly have temperature and precipitation changed in the Arctic in the past?

What do these past rates of change tell us about Arctic climate that can inform projections of future changes?

The climate record of the Earth shows changes that operate on many time scales, ranging from the tens of millions of years for drifting continents to rearrange themselves

on the planet, to the weeks over which the particles from a major volcanic eruption spread in the stratosphere to block the sun. This report summarizes paleoclimate data on past rates of change in the Arctic and subarctic on all relevant time scales, with special attention to characterizing the records of past abrupt changes that have had widespread impacts. This section of the report has been coordinated with CCSP Synthesis and Assessment Product 3.4, the complete focus of which is on global aspects of abrupt climate change.

The data used to assess rates of change in chapter 6 are primarily the same as those used to assess the magnitudes of change in chapter 5. However, as discussed in chapter 5, the existence of high-time-resolution records that cannot always be synchronized exactly to other records, and additional features of the paleoclimatic record, motivate separate treatment of these closely related features of Arctic climate history.

Faster or less expected changes have larger impacts on natural and human systems than do slower, better anticipated changes (e.g., National Research Council, 2002). Comparison of projected rates of change for the future (IPCC, 2007) with those experienced in the past can thus provide insights to the level of impacts that may occur. Chapter 6 summarizes rates of Arctic change in the past, compares these to recent Arctic changes and to non-Arctic changes, and assesses processes that contribute to the rapidity of some Arctic changes.

3) What does the paleoclimate record tell us about the past size of the Greenland ice sheet and its implications for sea level changes?

Paleoclimate data allow reconstruction of changes in the size of the Greenland ice sheet at various times in the past, and provide insight to the climatic conditions that produced those changes. This report summarizes those paleodata, and the implications for understanding of mechanisms that caused past changes and might contribute to future changes.

On land and in the ocean the ice sheet leaves tracks – evidence of its passage - showing how far it extended and when it reached that extent, (e.g., Denton et al., 2005). On land, moraines (primarily rock material) deposited around but in contact with the ice are especially important for documenting past ice extents. Beaches now raised out of the ocean following retreat of ice that previously depressed the land surface, and other geomorphic indicators, also preserve important information. Moraines and other ice-contact deposits in the ocean record evidence of extended ice; isotopic ratios of shells that grew in the ocean may reveal input of meltwater, and iceberg-rafted debris identified in sediment cores can be traced to source regions supplying the icebergs (e.g., Hemming, 2004). The history of ice thickness can be traced by moraines or other features on rock projecting above the level of the ice sheet, by the history of land rebound following removal of ice weight during deglaciation, and by indications (especially total gas content) in ice cores (Raynaud et al., 1997). Models can also be used to assimilate data from coastal sites and help constrain inland conditions. This report integrates these and other sources of information on past changes in the Greenland ice sheet.

Changes in glaciers and ice sheets, especially the Greenland ice sheet, would have global impacts. Complete melting of the Greenland ice-sheet would raise global sea level by 7 m; even partial melting would impact the world's coasts (Lemke et al., 2007). Freshwater

from ice-sheet melting delivered to the oceans in key sensitive regions—the North Atlantic Ocean, for example—could contribute to important changes in sea ice extent, ocean circulation, and climate, with strong regional and possibly global impacts (Meehl et al., 2007).

4) *What does the paleoclimate record tell us about past changes in Arctic sea ice cover, and what implications does this have for consideration of recent and potential future changes?*

This report documents past periods when Arctic sea ice extent was reduced, and evaluates the scope, causes, and effects of these reductions (e.g., CAPE, 2006). Past sea ice extent, and patterns or sea-ice drift, are recorded in sediments preserved on the sea floor. Sea ice extent can also be reconstructed from fossil assemblages preserved in ancient beach deposits along many arctic coasts (Brigham-Grette and Hopkins, 1995; Dyke et al., 1996).

Recent advances in tapping the Arctic paleoceanographic archives, notably the first deep-sea drilling in the central Arctic Ocean (Shipboard Scientific Party, 2005) and the 2005 Trans-Arctic Expedition (Darby et al., 2005), have provided new, high-quality material with which to identify and characterize warm, low-ice events of the past, which may serve as analogs for possible future conditions (e.g., Holland *et al.*, 2006). Sea ice fundamentally affects the climate and oceanography of the Arctic (e.g., Seager et al., 2002), the ecosystems, and human use, with implications extending across the Arctic and beyond, and reaching to such issues as national security and search-and-rescue (National Research Council, 2007).

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222 **3.4 Report and Chapter Structure**

223 This report is organized into 5 primary technical chapters. The first of these
224 (Chapter 4) is intended to provide a conceptual framework for the information presented
225 in the succeeding chapters, each of which focuses on one of the topics described above.
226 Chapter 4 also contains information on the standardized use of timescales and geological
227 terminology in this report.

228 Each of the topical chapters (Chapters 5 through 8) is organized to answer the
229 questions ‘Why, how, what, and so what?’ The ‘Why’ or opening introductory segment
230 for each chapter outlines the relevance of the topic to the issue of modern climate change.
231 The ‘How’ segment discusses the sources and types of data compiled to build the
232 paleoclimate record and the strengths and weaknesses of the information. The ‘What’
233 segment is the paleo-record information itself, presented in chronological order – oldest
234 to most recent – and the final ‘So what’ segment provides information on the significance
235 of the material contained in the chapter and its relevance to current climate change. Each
236 technical chapter is preceded by an abstract, which outlines the principal conclusions and
237 highlights from the body of the chapter itself.

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239 **3.5 The Synthesis and Assessment Product Team**

240 Four of the Lead Authors of this report were constituted as a Federal Advisory
241 Committee (FAC) that was charged with advising the USGS and the CCSP on the
242 scientific and technical content related to the topic of the paleoclimate history of the
243 Arctic as described in the SAP 1.2 prospectus. (See Public Law 92-463 for more

244 information on the Federal Advisory Committee Act, and the GSA website
245 <http://fido.gov/facadatabase/> for specific information related to the SAP 1.2 Federal
246 Advisory Committee.) The FAC for SAP 1.2 enlisted input from over 30 contributing
247 authors in 5 countries. These authors provided substantial content to the report, but did
248 not participate in the Federal Advisory Committee deliberations upon which this SAP
249 was developed.
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